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Influence of window size on the energy balance of low energy houses

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Abstract

A generally accepted way of building passive houses has been to have small windows facing north and large windows to the south. This is to minimize losses on the north side while gaining as much solar heat as possible on the south. In spring 2001, 20 terraced houses were built outside Gothenburg partly in this way. The indoor temperature is kept at a comfortable level by passive methods, using solar gains and internal gains from household appliances and occupants. Heat losses are very low, since the building envelope is well insulated and since modern coated triple-glazed windows have been installed.

The purpose of this work was to investigate how decreasing the window size facing south and increasing the window size facing north in these low energy houses would influence the energy consumption and maximum power needed to keep the indoor temperature between 23 and 26 °C. Different orientations have been investigated as well as the influence of window type.

A dynamic building simulation tool, DEROB-LTH, was used and the simulations indicate an extremely low energy demand for the houses. The results show that the size of the energy efficient windows does not have a major influence on the heating demand in the winter, but is relevant for the cooling need in the summer. This indicates that instead of the traditional way of building passive houses it is possible to enlarge the window area facing north and get better lighting conditions. To decrease the risk of excessive temperatures or energy needed for cooling, there is an optimal window size facing south that is smaller than the original size of the investigated buildings.

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Keywords: Energy efficient window; Low energy window; Building simulation; DEROB-LTH; Window size

1. Introduction

Passive Houses are buildings which ensure a comfortable indoor climate in summer and in winter without needing a conventional heating system. To permit this, it is essential that the building's annual demand for space heating does not exceed 15 kWh/m^2 year [1]. This minimal heating requirement can, for instance, be supplied by heating the supply air in the ventilation system—a system which is necessary in any case. When building passive houses a common technique is to let a large window area face south and to use small windows facing north to minimize the heat losses through the windows. As the *U*-values of the building envelope components have become lower over the years, this might not be as critical anymore.

Outside Gothenburg, Sweden, 20 terraced houses were built in spring 2001. Situated 5 min from the sea and 20 min by bus from the city it is no wonder that some of the tenants have chosen to live there because of the location [2]. The houses were designed to minimize the energy demand for heating by using the best available building technology. A picture of them can be seen in Fig. 1 showing the south façade which has a relatively large window area. The glass

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Fig. 1. The terraced houses in Lindås, Gothenburg. The overhanging roof and the glass rails of the balconies optimize the use of the solar energy.

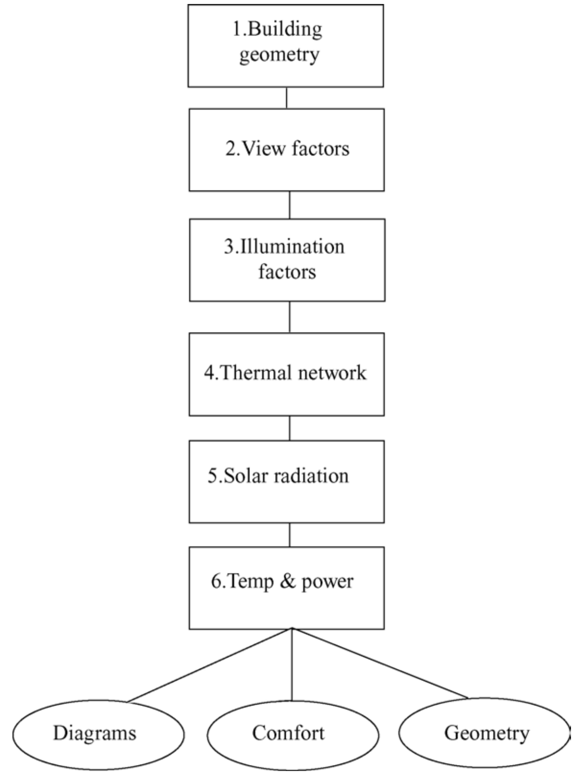

Fig. 2. The different calculation modules of DEROB-LTH.

balcony rails were designed not to shade the windows. On the north façade the window area is smaller than normal, to minimize heat losses. The roof overhang and the balconies prevent the rooms from overheating during the summer period, but do not reduce the incident radiation during the winter when the sun is lower.

With extra thick insulation and a very air tight construction, the houses were designed to keep warm without a traditional heating system. All this required very strict quality control since any uncontrolled air leakage would result in heat losses. This was made possible through close cooperation between the different parties involved in the project. The body heat from the occupants together with their use of electrical equipment producing heat was then assumed to be enough to keep the indoor temperature at 20 °C. An electric booster heater of 900 W was installed in the ventilation system as backup during the coldest winter days. The ventilation system was also equipped with an efficient heat exchanger. Solar collectors were installed on the roofs to cover 50% of the hot water demand. All installed windows were modern energy efficient windows.

The purpose of this presentation is to evaluate the importance of the size and orientation of the window systems in the terraced houses from an energy point of view.

2. Dynamic energy response of buildings LTH (DEROB-LTH)

Dynamic energy response of buildings LTH (DEROB-LTH) [3] is a simulation tool for performing energy simulation on buildings. The program consists of six interacting calculation modules and three displaying routines (see Fig. 2). The modules are executed separately, which helps working faster with the program. If a new climate file is defined in the model, the geometry for the building does not have to be recalculated but can be used the way it was in the previous simulation.

The first module calculates the building geometry with the input data. In the second, the view factors for radiant heat transfer between the building surfaces are calculated. The third determines the distribution factors for short wave and long wave radiation between the surfaces of the building. The fourth holds the heat transfer properties and the fifth calculates the hour-by-hour distribution of solar radiation. The amount of energy needed for cooling and heating is stored in module six together with the hourly temperature values. The displaying programs produce diagrams, comfort pictures and a drawing of the building geometry.

The building is defined as different parts with one or more rooms in one volume (see Fig. 4). By using the solar gains, body heat and internal gains, it is possible to calculate the space heating and cooling demand that is necessary to provide in order to achieve the desired indoor temperature (see Fig. 3).

The solar radiation is divided into its diffuse and direct parts, which are treated separately. It can also be transmitted as short wave radiation between two rooms of the building, which is good for simulations on buildings with large window areas or with internal glazings. The detailed treatment of the solar radiation in the calculation process is a strength of DEROB-LTH.

The output is presented as hourly values for each volume. The heating and cooling demands are given in watt-hours and represent the heating/cooling demand that is needed to

Input
- Geometry of the building
- Thermal properties of materials
- Climate
- Ventilation air flows
- Set points for heating and cooling
- Internal gains (from occupants and appliances)

Output
- Space heating and cooling demand (kWh)
- Peak loads for heating and cooling (W)
- Temperatures (°C)

Fig. 3. Input and output for the dynamic building simulation tool DEROB-LTH.

keep a certain temperature. The energy calculated for cooling is the energy that an air condition unit would use to cool the building if doors and windows were closed. The cooling demand can also be seen as an indication of the overheating risk.

Peak loads for cooling and heating are also calculated. Peak loads are important to study when dimensioning heating and cooling equipment.

3. Simulation model

DEROB-LTH was used to simulate how the terraced houses would perform from an energy perspective over a whole year. The simulation tool is described in Section 2. A model of a mid house was constructed consisting of five volumes as shown in Fig. 4. The total floor area is 120 m^2, and the original window area is about 16% of this, which is more than what is recommended in the Swedish building regulations [4] for sufficient lighting conditions inside. The south window area, however, is much larger than the area facing north.

The building envelope was set up by defining the properties of the different elements in the walls, floor and roof. The windows were composed by the corresponding properties of the panes and gas layers in the triple-glazed units in the same way, and the frames were added as wall sections.

The defined simulation parameters are given in the following sections.

3.1. Location, orientation and climate

The houses are located in the south of Sweden and originally oriented with the large window area facing south. In the simulations the house has been oriented in different directions to investigate how this influences the energy demands. A climate file with hourly data from 1988, which is regarded as an average year for Gothenburg, was used. This was provided by the Swedish Meteorological and Hydrological Institute, SMHI.

3.2. Construction

The building construction is more air tight and more insulated than traditional houses in Sweden. The intermediate walls are the ones separating the apartments. They are defined as adiabatic walls since no heat is assumed to be transferred through them. Inside the house there are several internal walls. In Table 1 the different *U*-values of the construction elements have been specified.

3.3. Windows

Two different triple-glazed window combinations were installed. One combination is operable, i.e. it is possible to open for ventilation. The other glass combination is a fixed triple IG-unit. Both combinations consist of three 4 mm thick panes.

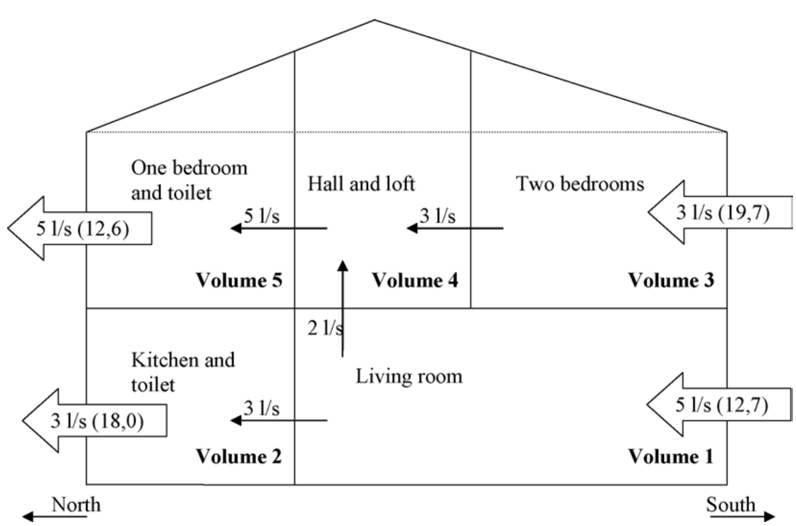

Fig. 4. Model of a mid house. The different rooms have been combined into five volumes, two in the ground floor and three in the second floor together with the loft. The wall facing south consists to a large extent of windows.

Table 1
The used U-values of the construction elements

	U-value (W/m^2, K)
Ground floor (excluding ground)	0.12
External wall	0.09
Roof	0.07
Intermediate wall (between units)	Adiabatic
Beam joist	0.65
Window frame	1.20
Glazing (operable)	0.74
Glazing (fixed)	0.54
Door	0.80

In the fixed window the middle pane of the IG-unit is ordinary clear float glass, while the outer and inner panes have a thin silver low-E layer facing the middle pane. The two gaps between the panes are filled with 90% krypton.

The operable combination consists of one single outer pane and one double IG-unit. The IG-unit is filled with 90% argon, while there is air in the ventilated space between the IG-unit and the outer pane. The pane in the IG-unit facing the room has a thin silver layer on its outer surface, as in the fixed combination, and the outer pane has a hard coating of tin oxide on its inner surface.

In DEROB-LTH the different windows were identified by the solar transmittance, reflectance and emittance of the panes and combining these with the gas fillings. The specified values of the different panes are listed in Table 2.

3.4. Shading

The houses are built with an extended roof, which prevents the solar radiation from entering the south facing windows during the summer, but lets it through during spring and autumn when the sun is lower. This shading is included in the simulation model, but no other external shading such as trees and other surrounding buildings has been included.

3.5. Internal gains and HVAC

Assumptions about the heat gains inside the house from electric appliances and body heat were made [5]. The year was divided into two periods, summer (June–August) and winter, with internal gains of 11.9 and 12.7 kWh/day, respectively. Furthermore, the tenants were assumed to be at home more during weekends than in the weekdays, which was also taken into consideration in the simulation model. In all simulations, a family of four persons, two adults and two children, were supposed to live in the house. The adults contributed by more body heat than the children.

Table 2
The three glass panes used in the different combinations

	T_{sol}	R	ε_{front}	ε_{back}
Clear	83	7	83.7	83.7
Low-e 4%	58	28	4	83.7
Low-e 16%	71	12	16	83.7

The transmittance, reflectance, back and front emittance are all given in percent.

Table 3
Schedule for internal gains coming from electrical equipment, persons in the volume and light

Hour	Internal gain (W)				
	Volume 1	Volume 2	Volume 3	Volume 4	Volume 5
Winter					
1–6	66	189	124	0	221
7–8	66	298	106	0	130
9–16	66	189	52	0	75
17–22	146	269	110	0	75
23–24	66	189	124	0	221
Summer					
1–6	66	189	124	0	221
7–8	66	298	106	0	130
9–16	66	189	52	0	75
17–22	106	229	110	0	75
23–24	66	189	124	0	221

It was suggested that the house should keep a minimum indoor temperature of 23 °C and a maximum indoor temperature of 26 °C. Normally 20 °C is considered as a standard indoor temperature, but the decision to increase the lower temperature set point to 23 °C for heating was due to the actual temperatures in the houses during the evaluation of the project [6].

The set point for cooling is defined as the temperature when the occupants are supposed to open windows and use shading devices.

The set points for indoor temperatures were kept constant to $T_{min} = 23\,°C$, $T_{max} = 26\,°C$ and the infiltration rate was 0.035 air changes per hour. The internal gains are summarized in Table 3. One adult person is assumed to contribute by 70 W and according to an occupancy schedule the available internal gains have been added to the table.

In practice, additional heat is supplied by the electric heater in the ventilation system, but other energy sources could also be used. Note that the terraced houses are not equipped with an active cooling system. The cooling of the houses is instead facilitated by ventilation through a skylight which, when opened in combination with opening one of the other windows gives rise to a chimney effect. This has not been modelled in this investigation.

4. Results and discussion

Low energy houses are built to minimize the energy demand for heating in temperate climates. Since they need less energy than an ordinary house they will also take less advantage of the free solar energy. Normally passive houses are built with larger window areas facing south to collect the solar energy, but in this case it is relevant to ask the question: *Does size matter*? In this section some results of the simulations will be presented and analyzed. The results are based on earlier work by the author of this article [2,7,8].

Because of the slightly higher minimum temperature of 23 °C (instead of 20 °C) more energy for heating is required than for similar standard simulations. The fact that the simulations were performed for a mid house reduces the same energy required if compared to an end house.

In all cases the total energy demand is still at a low level compared to most of the buildings that are built today. The mean energy demand for heating the houses in Linds was found to be 1642 kWh [9] from measurements by The Swedish National Testing and Research Institute, while a Swedish terraced house built by today's standard uses 5088 kWh [10] for the same living area.

4.1. Orientation

As mentioned above, large window areas are often installed into the south façades of a building to gain solar energy, while the area facing north is smaller. Since extra energy is needed mostly in the cold months when there is less solar radiation available at high latitudes, the orientation of the large glass façade is of less importance in this case and so is the size of the windows. To further investigate this we have simulated the terraced house in different orientations.

In Fig. 5 the annual energy demands for heating and cooling are shown for different orientation of the houses. In the figure, the positive axis represents the heating demand and the negative axis the cooling demand. It is shown that less energy is needed for heating if the houses are placed with the large window area facing south. Orienting the windows to the west or to the east does not influence the energy balance noticeably. It should therefore be possible to orient the houses differently without loosing too much energy. It should also be possible to distribute the window area more evenly, i.e. decrease the window area facing south and increase the area facing north.

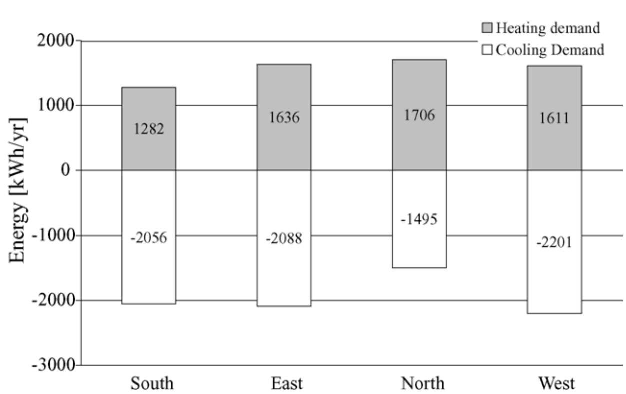

Fig. 5. Annual heating and cooling demand for different orientations of the large glass area of the houses in Linds, which is normally facing south, for Gothenburg climate.

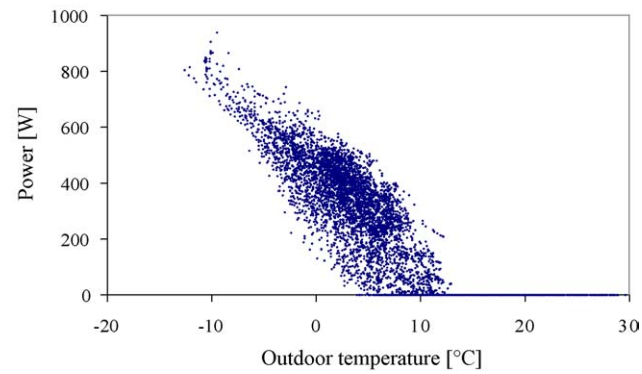

Fig. 6. The power needed vs. outside temperature for the houses in Lindås oriented so that the large glass area faces north. The dots correspond to hourly values needed for heating during the year.

The peak power demand is of great importance for the performance of this kind of building. In Fig. 6 the power needed for heating is shown for the house oriented so that the glass façade faces north. It can be seen that the peak power is only 950 W, and this is needed only for 1 h of the simulated year. All the values are extremely low and can, for example, be compared to the power of an ordinary microwave oven. This shows that the houses perform very well even with a large window area facing north and implies that the window area facing north could be increased in the original design to bring in more light from this side. Further investigations are necessary to find out how this will influence the energy demand and the daylighting in each of the rooms. Corresponding values for the houses oriented to the south are shown in Fig. 7 and they are slightly lower. The values are also more scattered because of a higher contribution from the sun on cold but sunny days in this direction.

4.2. Window size

It would take almost twice the amount of energy to heat the houses if normal uncoated triple-glazed windows were used instead of the low-e windows that are now used (see Fig. 8). By comparing the case of *no windows south*with the original one with *energy glass*, it is shown that using energy

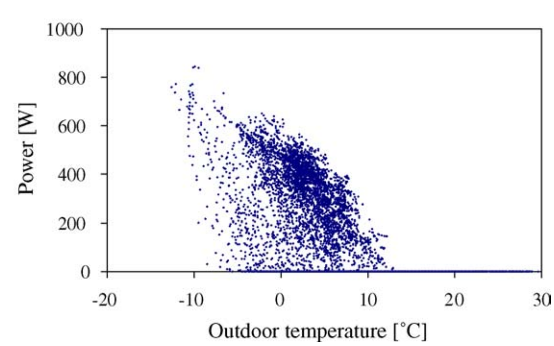

Fig. 7. The power needed vs. outside temperature for the houses in Lindås oriented so that the large glass area faces south. The dots correspond to hourly values needed for heating during the year.

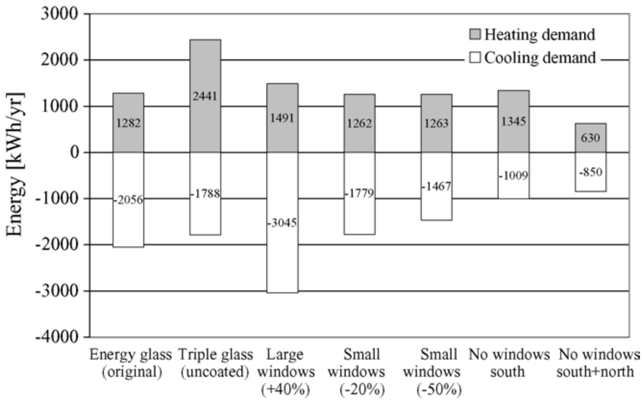

Fig. 8. Annual energy demands for different energy glass areas. Triple uncoated glass as well as an extreme case with no windows at all, no windows south + north, were also simulated. An optimum regarding space heating demand can be found somewhere between a reduced area of 20 and 50%.

efficient windows can be even better than having a highly insulated wall without windows. This is because the window can collect and use solar energy for heating the houses during periods when the sun is shining and the outdoor temperature is lower than the indoor temperature.

Reducing the window glass area facing south by 20% or even 50%, shows that this area does not influence the annual heating demand all that much. This is due to the well-insulated walls, which have a U-value of 0.09 W/m^{2}K, the excellent windows and the efficient ventilation system, which all together minimize the energy demand for the houses. Maximum energy demand occurs in the winter, when the sun shines less than during other parts of the year and therefore the houses do not make use of as much solar energy as a less insulated house would. A case with most of the south façade covered with energy glass has also been simulated, *large windows* in Fig. 8, which in fact needs more energy not only for cooling but also for heating over the year. In the model, only the glass area was increased and the frame area was kept the same as in the original case for simplicity.

Trying an extreme case with no windows at all, *no windows south + north*, it can be seen that this would be the most energy efficient way of building looking at both cooling and heating energy, but would be unrealistic. An optimum size of the windows should lie somewhere in between the original size and a reduced area of 50%, looking from an energy point of view (see Fig. 8). Looking at daylight the size might be different, but this has not been investigated here.

It is not only important to look at the annual energy need of the buildings, but also to estimate the maximum power needed to keep the desired indoor temperature. If this power can be reduced the installation costs for a heating or cooling system can be reduced.

In Fig. 9 the heating load on a cloudy day in January is shown for different sizes of the windows. The outdoor temperature varies between −2 and 0 °C. No important

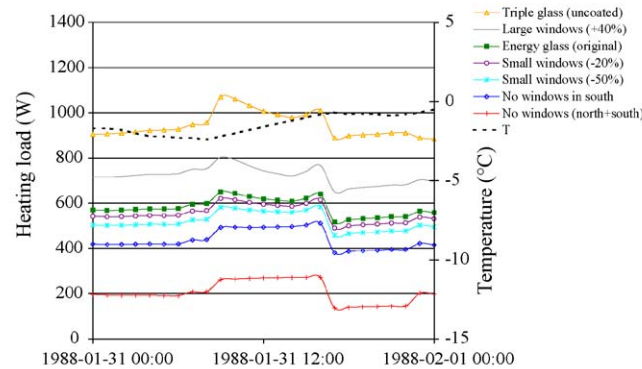

Fig. 9. The heating load on a cloudy winter day in January for different window sizes facing south. The cases of triple uncoated glass, no windows south and no windows north + south are shown too. A smaller or larger size of the window area would not affect peak load dramatically.

difference can be seen for the cases with much smaller windows and the larger window area. The larger area would give a higher peak load, but it is still lower than for the case with triple clear glass windows. No windows at all would give a much lower peak load, but this is an unpleasant and unrealistic situation. It is also possible to see how the load increases as the outdoor temperature decreases in the morning hours.

Fig. 10 presents the heating load a sunny but cold day in December for different window areas. The outdoor temperature varies between −11 and −6 °C. The peak loads for different window areas are still similar to each other but the larger area would need a higher peak load in the morning and a lower load in the evening compared with the other alternatives. For all different window areas the sun helps to heat the house during the day. The northern windows do not contribute at all at this time of the year which can be the conclusion by comparing the case of no windows (south + north) and no windows (south).

The cooling load during a day in June is shown in Fig. 11. The outdoor temperature varies between 17 and 28 °C. The case with no windows at all (south + north) would give the

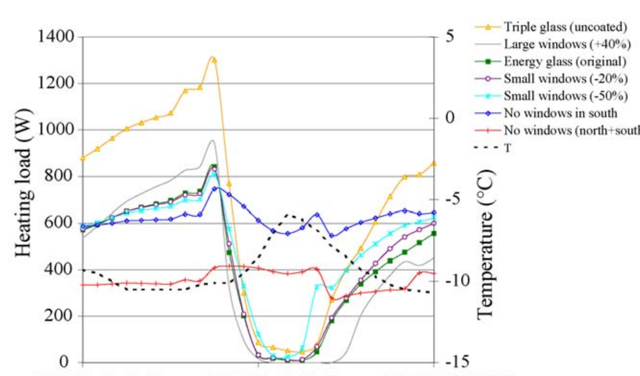

Fig. 10. The heating load a sunny winter day in December for different window sizes facing south as well as for triple uncoated glass and no windows. A smaller or larger size of the window area would not affect the peak load dramatically.

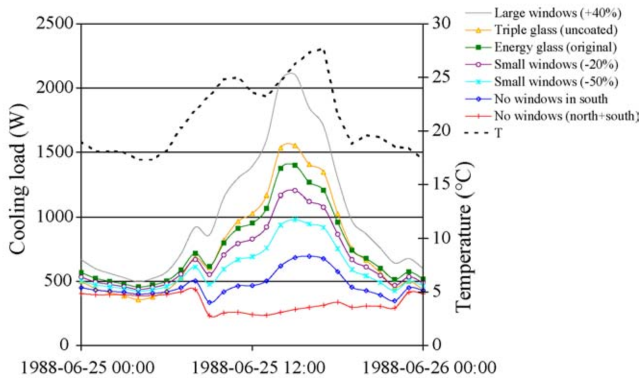

Fig. 11. The hourly power needed for cooling the house during a summer month for different window sizes facing south as well as for triple uncoated glass and no windows. A smaller size of the window area reduces the maximum power needed for cooling.

lowest cooling power demand. A big difference can be seen between the different sizes of the windows. A larger glass area of 40% means more than double the cooling power compared to the case of a 50% reduced window area. In the model was no extra ventilation applied, which gives a higher load than it would be for the houses in reality.

5. Conclusions and outlook

The terraced houses in Gothenburg work extremely well. The space heating demand to keep a temperature of 23 °C is 1282 kWh for a mid house, which is much below a standard house of this size. Good thermal insulation of a house reduces the need for solar radiation to keep the house warm, and the terraced houses are extremely well insulated. This is why the sun is of moderate importance for raising the indoor air temperature, and it is possible to reorient the houses by 180 ° without noticing any significant change in their energy balance. If the tenants prefer having larger windows to the north, for instance, this would cost very little extra energy for heating, as long as energy-efficient windows are used.

The peak loads are important for this type of building and it has been shown that these houses manage with a booster heater of only 900 W. The size of the windows does not influence the peak power for heating noticeably. However, using a larger window area facing south would necessitate an increased ventilation rate and use of shading devices to reduce excessive temperatures, or increase the power needed for cooling during the summer.

The simulations indicate that a window area to the south could be found, which is optimal from an energy point of view. This area is smaller than the present area but larger than half of the present area. Solar gains through the windows contribute to the space heating, and it is important not to reduce the total window glass area. A smaller window area could significantly reduce the available daylight. As a rule of thumb, the glass area should not be less than 10% of the floor area [4]. It is possible to distribute the area differently between the façades and rooms, since it is not crucial for the heating demand or peak load to have large windows facing south.

Looking only at the cooling requirement, the optimum would be to reduce the window glass area toward south to 0, but that would be unrealistic. Using shading devices would be a good complement during the summer as well as sunny days during spring and fall to reduce the cooling demand. It is very easy to air the studied terraced houses, which means that the cooling demand is of less significance than the heating demand. If these houses are built in a warmer climate with more solar radiation, and where air-conditioning might be used, it is important not to choose too large windows to keep the maximum power for cooling down.

In this work only the window area facing south has been varied and it has been found that there is an optimum size. It is probable that there is an optimum area for all of the orientations of the windows. Performing daylighting simulations could find the optimized size for a comfortable light situation in the houses, which may not be the same as the one found from an energy perspective [11].

It would be interesting to build similar houses with similar windows, but with more of these windows facing north than today and less window area facing south to get a better distribution of the light. The same building strategy could also be applied to detached houses, in which case windows could be orientated in all directions.

Other cold climates with more solar irradiation during the winter, such as northern USA and southern Canada could yield different results. It is the subject of a further study to investigate how a similar house would perform in other climates.

Another interesting question is how the window area influences the energy balance of a standard terraced house. What is the optimum window area for a poorly insulated house or a house strongly shaded by surrounding buildings?

In modern office buildings the window area has grown and fully glazed façades are now frequently used to achieve high daylight levels inside and to obtain an attractive appearance of the buildings. This creates a problem of overheating, which can be partly prevented by different kinds of solar shading, but an acceptable indoor environment is in practice reached by air conditioning. This, however, costs us a lot of energy and some of it could be saved by choosing energy efficient windows, such as solar control windows. In the future switchable windows [12] could be used, which have the possibility of varying the transmittance of solar radiation and can in this way minimize the heat coming from the outside through the window during sunny days. In this case the window size is also an interesting issue.

This article is meant to give guidance in the process of choosing windows by evaluating the influence of the window area and type on the energy use. A positive outcome is that it is not so important to keep down the window area facing north, and thus the architect has more flexibility in choosing the orientation of the building and the positioning of the windows.

Acknowledgements

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